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# Molecular beam epitaxy (MBE) of quantum devices

*A. Y. Cho*, D. L. Sivco, H. M. Ng, C. Gmachl, A. Tredicucci,
R. Colombelli and F. Capasso

Bell Laboratories, Lucent Technologies 600 Mountain Avenue,
Murray Hill, NJ 07974 USA

Molecular beam epitaxy (MBE) is a thin film process for the growth of single crystalline semiconductor, metal, and insulator materials. A unique feature of MBE is the ability to prepare layers with atomic precision. The film grows atomic layer by atomic layer. This allows us to achieve "band structure engineering" and it is the basis of many high-performance semiconductor devices such as high-speed electronic circuits, lasers, and detectors.

One illustration of the demanding structures grown by MBE is the Quantum Cascade (QC) Laser. This laser is fundamentally different from conventional lasers in that it can be tailored to emit light at a specific wavelength by simply varying the quantum well width using the same combination of semiconducting materials. The quantum wells may be as thin as 10 Angstroms and the whole QC laser may be composed of over five hundred precise layers. This can only be achieved by computer controlled MBE. With InGaAs for the well and InAlAs for the barrier, we have demonstrated emission wavelengths from 3.5 $\mu$m to 24 $\mu$m. The highest peak optical power we have obtained is 2 W pulsed and 0.5 W cw. The highest operating temperature was demonstrated at 425 K for an 8.4 $\mu$m laser with an output power of 17 mW.

Most of the QC lasers made today are with InGaAs/InAlAs and GaAs/AlGaAs systems. In order to achieve shorter wavelength, intersubband transitions useful for the fiber communication wavelength, we have to extend the material system to GaN/AlGaN, which has a maximum conduction band offset of 2 eV. Preliminary studies of that system will also be discussed.

MBE is now a high volume production technology for microwave and photonic quantum devices. Multi-wafer, computer controlled high throughput MBE systems can automatically grow as many as seven 6″ or fifteen 4″ wafers on each platen with uniformity and reproducibility within 1%.